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PERSISTENCE OF DICHLOBENIL IN LAKE SEMINOLE, GEORGIA

by

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Dichlobenil is a herbicide being considered for use in large aquatic systems for control of submersed plants. Granular formulations of dichlobenil are incorporated in the sediment, causing injury and death in young germinating plants. The persistence of dichlobenil was evaluated in the water and sediment of eleven 0.4-ha plots in Lake Seminole, Georgia, in June 1986. Dichlobenil residue concentrations within the treated water column were found to have a half-life of between 7 and 9 days. Concentrations were greatest between 1 and 5 days posttreatment and dissipated by 21 days posttreatment. Dichlobenil residue concentrations in the sediment were found to have a half-life of between 16 and 28 days. Concentrations were greatest immediately after treatment and dissipated by 55 days posttreatment in half of the plots and by 104 days posttreatment in the remaining plots. Dichlobenil appeared to impair the vegetative regrowth and reinfestation of hydrilla and

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watermilfoil following chemical defoliation of the mature vegetative standing crop with endothall. The relatively low dichlobenil residue concentrations in the water and the persistence characteristics in both the water and sediment suggest that the operational use of dichlobenil for control of submersed aquatic plants will not cause harm to associated nontarget organisms.

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Aquatic plant management	Hydrilla	2,6-dichlorobenzonitrile
Dichlobenil	Lake Seminole, GA	Watermilfoil
Herbicide	2,6-dichlorobenzamide	

Preface

This study was conducted by personnel of the US Army Engineer Waterways Experiment Station (WES) and was funded by the US Army Corps of Engineers Aquatic Plant Control Research Program (APCRP). Mr. E. Carl Brown, US Army Corps of Engineers, was Technical Monitor.

The objective of the study was to evaluate the persistence of dichlobenil in the sediment and water of Lake Seminole, Georgia, when applied to submersed aquatic plants, under operational conditions. Results from this study will be of use in determining the experimental design of future field studies required for the registration of dichlobenil for aquatic use.

This work was initiated in June 1986 under the general supervision of Dr. John Harrison, Chief, Environmental Laboratory (EL), and Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division (ERSD), and under the direct supervision of Dr. Thomas L. Hart, Chief, Aquatic Processes and Effects Group (APEG), ERSD. Mr. J. Lewis Decell, EL, was Program Manager for the APCRP. Technical reviews were provided by Drs. Kurt Getsinger, Kien Luu, and George Pesacreta of the APEG. The report was edited by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

The principal investigator for this work was Dr. Howard E. Westerdahl, APEG. Mr. W. Reed Green, employed under an Intergovernmental Personnel Act agreement with the Water Resources Research Center, University of Arkansas, was primarily responsible for conducting the study and prepared the report. Mr. Kyle Bertrand, APEG, assisted in the field sampling. Field assistance was also provided by the personnel at the US Army Engineer (USAE) Project Office, Lake Seminole, Georgia. Mr. Paul King, applicator and consultant, assisted in the application of the herbicides under contract with the USAE District, Mobile. The dichlobenil residues were analyzed by Duphar B.V. of the Netherlands. Duphar B.V. and Pennwalt Corporation provided the herbicides used in this study.

Commander and Director of WES was COL Dwayne G. Lee, CE. Technical Director was Dr. Robert W. Whalin.

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PERSISTENCE OF DICHLOBENIL IN LAKE SEMINOLE, GEORGIA

Introduction

1. The herbicide dichlobenil (2,6-dichlorobenzonitrile) has been used to control aquatic plants for the past two decades in Europe, North America, and Australia. The chemical is registered by Duphar B.V. of the Netherlands and is licensed in the United States by Uniroyal Chemical and PBI Gordon, Inc., under the tradenames of CASORON and NOROSAC, respectively. Current label restrictions, however, prevent the application of dichlobenil where water is used for livestock and human consumption. Therefore, dichlobenil will not be used by Federal and state agencies until an allowable water residue level for drinking water and nontarget organism tolerance levels are established and the formulation is registered with the US Environmental Protection Agency (USEPA). It is expected that, when registered, dichlobenil will provide an additional method for controlling submersed aquatic plants (e.g., hydrilla, *Hydrilla verticillata* L.f. Royal, and watermilfoil, *Myriophyllum spicatum* L.). The incorporation of dichlobenil within the sediment and the accumulation of the residues by the root system of plants should be an effective mechanism in managing submersed aquatic plants in flowing water environments.

2. The study described herein was a cooperative effort, between the US Army Engineer Waterways Experiment Station and Duphar, to obtain preliminary data that would assist in developing plans (type, frequency, and sampling regimes) for later studies to be conducted under an Experimental Use Permit issued by the USEPA.

Objectives

3. The primary objective of this study was to evaluate the residue persistence of dichlobenil and its metabolite 2,6-dichlorobenzamide in the sediment and water of Lake Seminole, Georgia, when applied under operational conditions, using small experimental plots. In relation to this objective, dichlobenil and 2,6-dichlorobenzamide residue persistence was compared with information from the literature, to better define and evaluate the potential

environmental fate and effects of the residues. As a secondary objective, herbicide efficacy was qualitatively evaluated to determine dichlobenil's applicability in controlling mature, standing vegetation and to ascertain dichlobenil's ability to control the sequential regrowth and reinfestation of vegetation following endothall application and vegetative knockdown.

Dichlobenil

Chemistry and mode of action

4. Dichlobenil (Figure 1) is a white, crystalline solid, both thermal- and photo-stable. It is soluble in water at 18 mg/ℓ at 20° C and is volatile, with a vapor pressure of 5.5×10^{-4} mm Hg at 20° C (Verloop 1972). Evaporation of the chemical is enhanced in the presence of water, and dichlobenil has a strong adsorption affinity both in aqueous solution and in the vapor phase. The major by-product of dichlobenil metabolism is 2,6-dichlorobenzamide (Figure 1). Granular or pelletized formulations of dichlobenil used in aquatic applications range from 4 to 20 percent active ingredient (ai). When applied to aquatic systems, the pellets sink to the sediment where most of the chemical becomes incorporated.

5. Dichlobenil is a nonselective, broad-spectrum herbicide that affects both monocotyledonous and dicotyledonous plants (i.e., grasses and broadleaf plants). It is a herbicide that is absorbed through the soil or sediment by the roots and affects areas of active cell division in both the roots and stems. Dichlobenil has its greatest activity and highest efficacy in germinating seeds, young seedlings, and germinating propagules that originate from stolons, tubers, and rhizomes.

6. Uptake, translocation, sites of accumulation, and metabolism of dichlobenil vary among plant species (Mottley and Kirkwood 1978). Dichlobenil activity in the plant is related to the rate of translocation, the levels of tissue accumulation, the plant's ability or inability to release the chemical through vapor loss, and the plant's ability to metabolize dichlobenil into inactive by-products. Following root accumulation, the herbicide is translocated through the xylem of the vascular system to the stems and leaves. Metabolic breakdown of dichlobenil generally occurs in the leaves through hydroxylation and phenol conjugation (Verloop 1972). Dichlobenil release

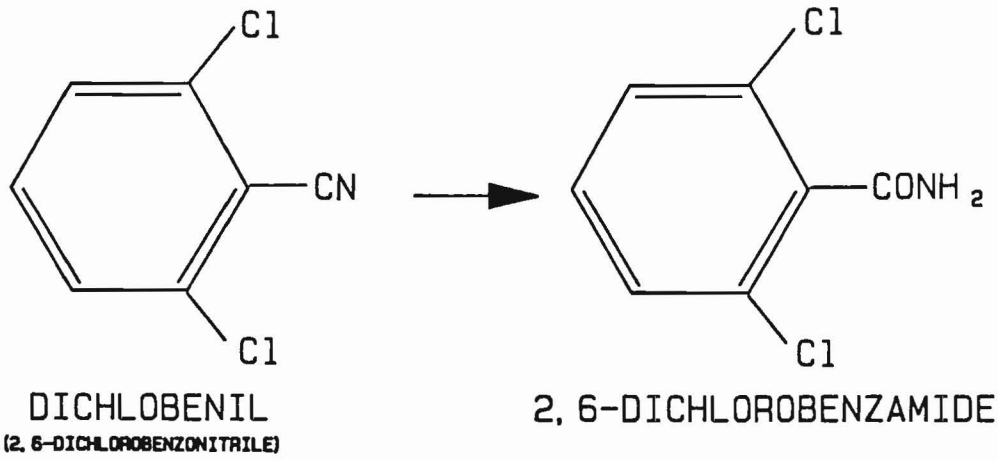

Figure 1. Dichlobenil and its primary metabolite

occurs through transpiration and vapor loss within the leaves of terrestrial plants (Verloop 1972).

7. Visual symptoms of dichlobenil injury include the swelling of tissues, the blackening and death of growing tips, root and stem brittleness, and inhibition of root hair growth (Verloop 1972, Mottley and Kirkwood 1978). Verloop (1972) reported that dichlobenil applied to alligatorweed destroyed the phloem tissue, the vascular cambium, and associated parenchyma in the meristematic tissues. Van and Steward (1984) found that hydrilla tuber germination was not inhibited at aqueous dichlobenil concentrations of up to 1.0 mg/ℓ, but development of newly germinating sprouts was severely retarded even at low concentrations (0.05 mg/ℓ). Concentrations of 0.10 mg/ℓ or greater, applied to germinating plants, produced 87-percent or greater injury ratings. Dichlobenil's metabolite (2,6-dichlorobenzamide) uncouples oxidative phosphorylation, which disrupts photosynthesis (Verloop 1972). In some plants, metabolism of dichlobenil may reduce injury, allowing greater tolerance to the chemical (Sikka, Lynch, and Lindenberger 1974).

Environmental fate and persistence

8. Degradation of dichlobenil in the environment is dependent primarily on the rates of biotic metabolism. The half-life of dichlobenil, tested in eight sterilized, terrestrial soil types, varied from 1.5 to 12 months (Verloop 1972). The persistence was not related or controlled by pH,

percentage of organic matter, or clay or lime in the soil, indicating that degradation is a function of microbiological activity. When applied to a sandy soil, the by-product 2,6-dichlorobenzamide remained persistent at least 2 years (Verloop 1972) and, under the conditions studied, did not degrade further. Studies conducted in the aquatic environment (Satoru, Sikka, and Lynch 1975) indicate that dichlobenil can be metabolized through microbiological activity to carbon dioxide via 2,6-dichlorobenzamide.

9. The persistence, concentration, and dissipation of dichlobenil residues in the aquatic environment, in addition to being dependent on biotic metabolism, are influenced by water exchange and the volume of water treated in relation to the total volume of the system. These characteristics, which differ among aquatic systems and applications, will also influence the environmental fate of the residues (e.g., the accumulation of residues in fish and other nontarget organisms).

10. Dichlobenil residues in water, within treated areas, have been reported to reach their highest concentrations 2 to 3 weeks after application (Van Valin 1966; Cope, McCraren, and Eller 1969; Tooby and Spencer-Jones 1978; Terry, Robson, and Hanley 1981). Residues rapidly dissipate thereafter but remain in the water between 112 and 188 days. Van Valin (1966) suggested that the lag in peak concentrations is caused by the slow dissolution of the granular dichlobenil formulation within the sediment. In closed, quiscent systems, residues build up over time within the water until biotic metabolism becomes greater than dissolution from the sediment, reducing residue concentrations. In localized treatments where sections of treated water are surrounded by nontreated water, dichlobenil will diffuse or flow outside the treated areas, diminishing along a gradient (Tooby and Spencer-Jones 1978; Terry, Robson, and Hanley 1981). Residues released from the pellets into the overlying water and the dispersion outside the treated area accelerate dissipation and reduce residue buildup within the treated water.

11. Dichlobenil residues in sediment have been reported to reach their highest concentrations within the first few days after application (Van Valin 1966; Tooby and Spencer-Jones 1978; Terry, Robson, and Hanley 1981). Concentrations decline sharply after this and gradually stabilize around 3 weeks posttreatment, persisting to 140 and 166 days after treatment (Van Valin 1966; Cope, McCraren, and Eller 1969). Sediment residues are confined to the treated area, unlike water residues (Terry, Robson, and Hanley 1981). Bowmer

et al. (1976) reported that dichlobenil residues extended 10 cm into the sediment, resulting from an application under drawdown conditions.

12. Accumulation of dichlobenil in fish is relatively slow and directly related to residue levels in the water (Van Valin 1966, Tooby and Spencer-Jones 1978). Residues accumulated within fish are eliminated rather quickly when fish are placed in fresh water or when contaminated water is eventually replaced with fresh water (Tooby and Spencer-Jones 1978, Wiersma-Roem et al. 1978). Wiersma-Roem et al. (1978) determined that "high" concentrations of dichlobenil (0.71 and 1.28 mg/ℓ) affected the gill epithelium cells of rainbow trout (*Salmo gairdnerii* R.), causing tissue hypertrophy and hyperplasia. Residues were detected in muscle tissue, but these concentrations did not cause any harm to the fish. Experiments conducted by Tooby and Spencer-Jones (1978), using the fish "roach" (*Rutilus rutilus* L.), demonstrated that dichlobenil accumulated in various tissues (0.8 to 6.4 mg/kg), but the residue levels had no significant effect on the fish.

13. The metabolite 2,6-dichlorobenzamide is moderately toxic to a number of freshwater organisms: guppies, rainbow trout, daphnids, and algae (Van Leeuwen and Maas 1985). Concentrations differed among the organisms involved. The LC_{50} dose of 2,6-dichlorobenzamide for rainbow trout and guppies was determined to be 235 and 275 mg/ℓ, respectively (Van Leeuwen and Maas 1985). Concentrations of 18 mg/ℓ or greater reduced the survival and growth in rainbow trout embryos and larvae. Concentrations less than 320 mg/ℓ did not alter survival and reproduction in daphnids. Based on their results, Van Leeuen and Maas (1985) concluded that 2,6-dichlorobenzamide levels, resulting from normal field applications of dichlobenil, should not impose a great risk to aquatic life.

Materials and Methods

14. The study was conducted in the Spring Creek tributary of Lake Seminole (Figure 2) and was initiated in June 1986. The dominant aquatic macrophytes at the time were watermilfoil and hydrilla. Pondweed (*Potamogeton* sp.) and naiad (*Najas minor* All.) were also present. An experimental design was developed to address the objectives for conditions that would resemble those characteristic of dichlobenil applications.

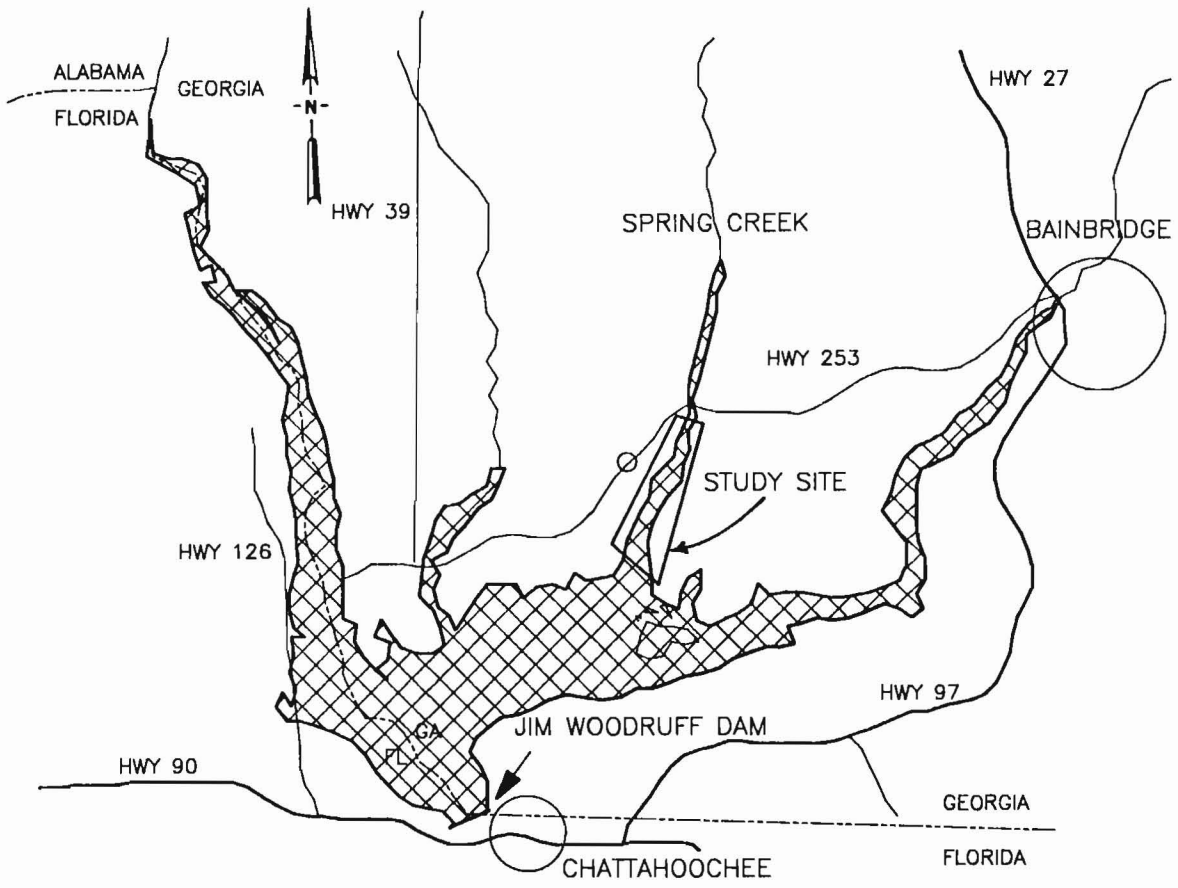

Figure 2. Sample site and plot locations

Normally, dichlobenil would be applied in the early spring, when the vegetation is very young and the water column is void of standing vegetation. Since the study was conducted in June, when the vegetation was already established and mature, it was decided to remove the standing crop using endothall (Aquathol K, Pennwalt Corporation), a commercially used aquatic defoliant, to evaluate dichlobenil persistence in bare (springlike) plots and observe herbicide efficacy on regrowth and reinfestation. Endothall was applied to six of eleven 0.4-ha test plots, 8 days prior to dichlobenil application. The liquid endothall was applied by trailing hose at a rate of 296 kg/ha to achieve an initial concentration of 3 mg acid equivalent (ae)/ℓ. The existing vegetation was left untreated in the remaining five test plots.

15. Two granular formulations of dichlobenil were chosen for evaluation: a commercially available 10-percent ai, CASORON 10G (Uniroyal Chemical) and an experimental 20-percent ai. Table 1 lists the experimental treatments along with their rates and the designated plots. Both dichlobenil formulations were applied at equivalent rates of 16.7 kg (ai)/ha to randomly selected

Table 1

Treatment Tests

Treatment*	Rate	Plot Nos.
E+20G	3 mg ae/ℓ (E) 16.7 kg ai/ha (20G)	1,2
E+10G	3 mg ae/ℓ (E) 16.7 kg ai/ha (10G)	5,8
20G	16.7 kg ai/ha	4,10
10G	16.7 kg ai/ha	9,11
E (Reference)	3 mg ae/ℓ	3,6
Reference		7

* E = endothall; 20G = dichlobenil 20-percent granular; 10G = dichlobenil 10-percent granular.

test plots. All tests were conducted in duplicate. Each of the dichlobenil formulations was applied in two of the six endothall-pretreated plots. The remaining two endothall plots were used as references against the four endothall plots with dichlobenil. Each of the dichlobenil formulations was also applied to two plots not previously treated with endothall (mature vegetation). A remaining untreated plot was used as a reference.

16. Each of the test plots was divided into four quadrants for dichlobenil and 2,6-dichlorobenzamide residue sampling in water and sediment. Water and sediment residue samples were not taken from the endothall-only reference plots (without dichlobenil), and no residue samples were taken outside the test plots. Water was collected using a 12-V DC positive displacement pump connected to a drinking water-quality hose with a screened intake. One-liter samples were collected at middepth from the center of each quadrant and mixed together in a glass container to provide one 1-ℓ composite sample. A separate 1-ℓ water sample was collected at middepth from the center of each plot to provide a second water sample. Sediment surface samples (top 5 to 10 cm) were collected using a spring-loaded, trapdoor scoop, in which several scoops from the center of each quadrant (as well as the center of the plot) were placed in a stainless steel bowl and mixed. A 1-ℓ composite sample was scooped from the bowl and added to a 1-ℓ steel container. Water samples

were collected on the pretreatment day, treatment day, and on posttreatment days 1, 5, 8, 12, 21, 34, and 55. Sediment samples were collected on the same schedule except on posttreatment days 5 and 8, and an additional sample day (posttreatment day 104) was included. Residue analyses were provided by Duphar B.V. according to the methods described by Van Rossum et al. (1978).

17. Empirical herbicide efficacy determinations were made on the same sampling days as the water and sediment samples and on posttreatment day 177. Evaluations were determined visually, based on pretreatment conditions, the reference plots (endothall without dichlobenil and the untreated reference), and the surrounding vegetative conditions. Estimations of percent total standing crop cover were made within the test plots and broken down to individual plant components: watermilfoil, hydrilla, and other (pondweed, naiad, etc.). The percent standing crop cover can be converted to percent control by subtracting the percent standing crop from 100. A percent cover of 100 would be equivalent to 0-percent control; conversely, a percent cover of 0 would be equivalent to 100-percent control.

18. Though water movement through the treated area was recognized as an important mechanism for herbicide transport and dissipation, delineation of water movement and assessment of its impact on residue persistence were beyond the scope of this study.

Results

Water residue analysis

19. Results of the dichlobenil water residue analysis are presented in Figure 3 and Table 2. No residues were detected in any of the pretreatment samples or within the reference plot during the sampling period. Residue half-life in water from the four dichlobenil treatments was between 7 and 9 days, and residue dissipation occurred by 21 days posttreatment. Maximum concentrations of dichlobenil residues in the water occurred soon after treatment. The highest residue concentration on the treatment day (86 µg/ℓ) occurred in a 20G plot. Residue levels in the sediment increased in four of the eight test plots on posttreatment day 1, while the other four plots contained either equivalent or slightly decreased concentrations. The highest concentration on posttreatment day 1 (85 µg/ℓ) occurred in the same 20G plot mentioned above. Maximum concentrations of 83 and 58 µg/ℓ occurred in two

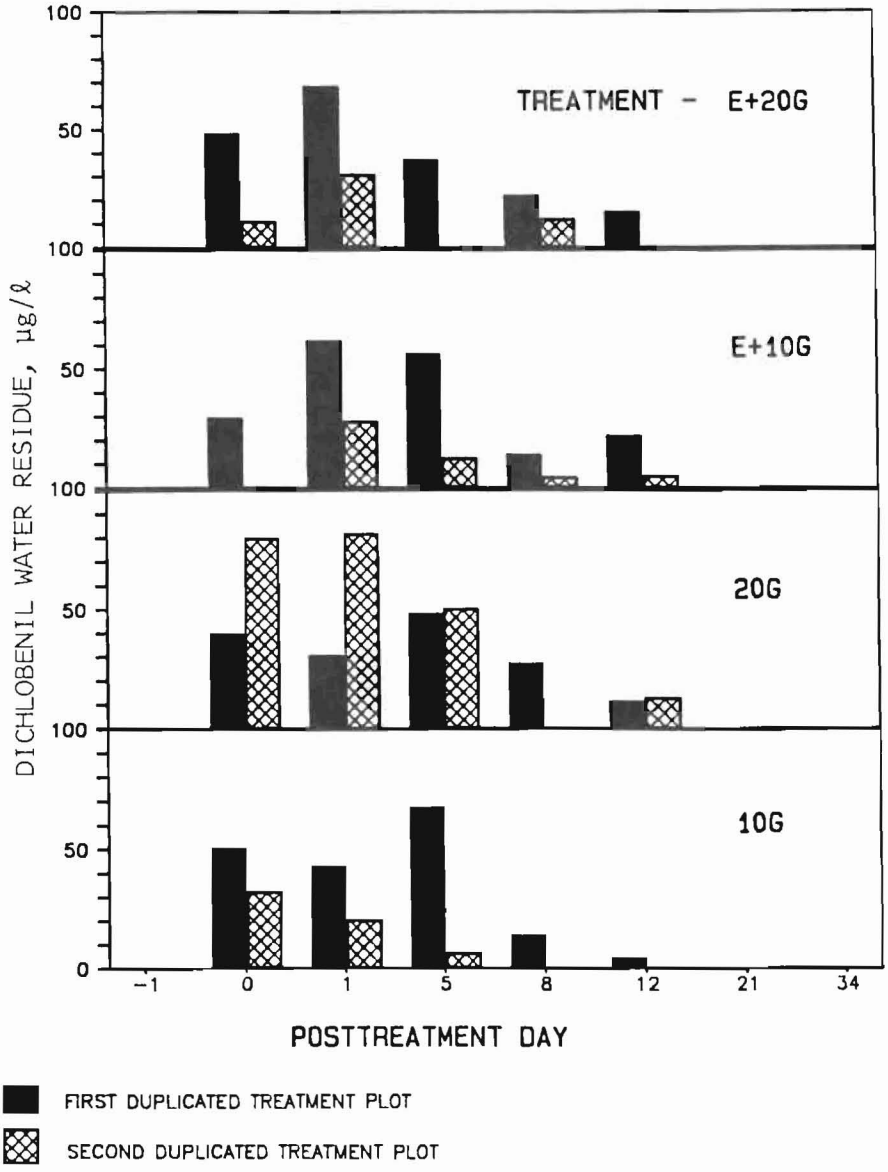

Figure 3. Dichlobenil water residues

test plots (one 10G and one 20G, respectively) on posttreatment day 5. Dichlobenil concentrations decreased in all plots between 5 and 12 days post-treatment. Dichlobenil residues ranged between nondetection and 24 µg/ℓ on posttreatment day 12. On posttreatment day 21, residues were below detection limits in all treated plots.

Table 2

Water Residue Analysis: Dichlobenil*

Treatment	Plot No.	Sample Locale**	Sample Day -1	0	1	5	8	12	21	34	55
Reference	7	Center	<10	<10	<10	<10	<10	<10	<10	<10	<10
		Quadrant		<10	<10	<10	<10	<10			
E+20G	1	Center		49	73	48	25	17			
		Quadrant		49	65	28	20	14			
	2	Center		<10	50	<10	13	<10			
		Quadrant		23	13	<10	12	<10			
E+10G	5	Center		35	77	58	<10	21			
		Quadrant		25	48	56	29	24			
	8	Center		<10	50	<10	13	<10			
		Quadrant		23	13	<10	12	<10			
20G	4	Center		35	35	58	42	12			
		Quadrant		46	28	40	14	12			
	10	Center		75	85	50	<10	15			
		Quadrant		86	80	52	<10	12			
10G	9	Center		52	35	83	16	10			
		Quadrant		50	52	53	13	<10			
	11	Center		38	18	<10	<10	<10			
		Quadrant		28	24	14	<10	<10			

* Corrected values expressed in micrograms per liter (10 µg/ℓ detection limit at 113-percent recovery).

** Center = center plot sample; Quadrant = composite sample from the center of each quadrant.

20. The metabolite 2,6-dichlorobenzamide (13 µg/ℓ) was detected in only one water sample, from one of the 10G plots (plot 9, center) on posttreatment day 5. No other water samples contained detectable levels of this by-product.

Sediment residue analysis

21. Dichlobenil residues in the sediment were relatively higher than those of the water, and dissipation occurred over a longer period of time. The half-life of the dichlobenil residues in the sediment was between 16 and 28 days among the four treatments. Dissipation below the detection limit (0.01 mg/kg) occurred by 55 days posttreatment in the E+20G and 10G treatments, and by 104 days after treatment in the E+10G and 20G treatments (Figure 4 and Table 3). Residues were not detected at any time during the study in the sediment in any of the pretreatment samples or the untreated reference plot. Residue levels in the sediment reached maximum concentrations early after treatment, either on the day of treatment or posttreatment day 1. On treatment day 0, a sample taken from one of the E+20G plots contained a dichlobenil residue concentration of 8.63 mg/kg. All other sediment samples on this day were at or below 1.43 mg/kg. The largest concentration measured in the study (12.10 mg/kg) occurred in a sample taken from the same E+20G plot previously mentioned, on posttreatment day 1. All other samples on posttreatment day 1 were at or below 0.82 mg/kg. By day 8, residue levels dropped to or below 0.30 mg/kg, with the exception of the sample taken from the previous E+20G plot, which contained 0.99 mg/kg. By day 21, all sediment samples were at or below 0.10 mg/kg, again with the exception of a sample taken from the E+20G plot that contained 0.31 mg/kg.

22. The metabolite 2,6-dichlorobenzamide was detected (>10 µg/kg) in a number of sediment samples (Table 4). Only those plots treated with dichlobenil contained detectable quantities of the metabolite. The E+20G plots had the highest frequency of detectable samples (10 of 14). The 10G plots without endothall pretreatment had the lowest frequency (1 of 14). The highest concentration (66 µg/kg) was found in one of the E+20G samples on posttreatment day 34 and in an E+10G sample on day 55. Only two of the eight dichlobenil-treated plots, an E+20G and an E+10G plot, contained residues of the metabolite at 104 days posttreatment. The highest concentration of the 2,6-dichlorobenzamide detected in a plot was 0.5 percent of the maximum concentration of dichlobenil detected within the same test plot during the study.

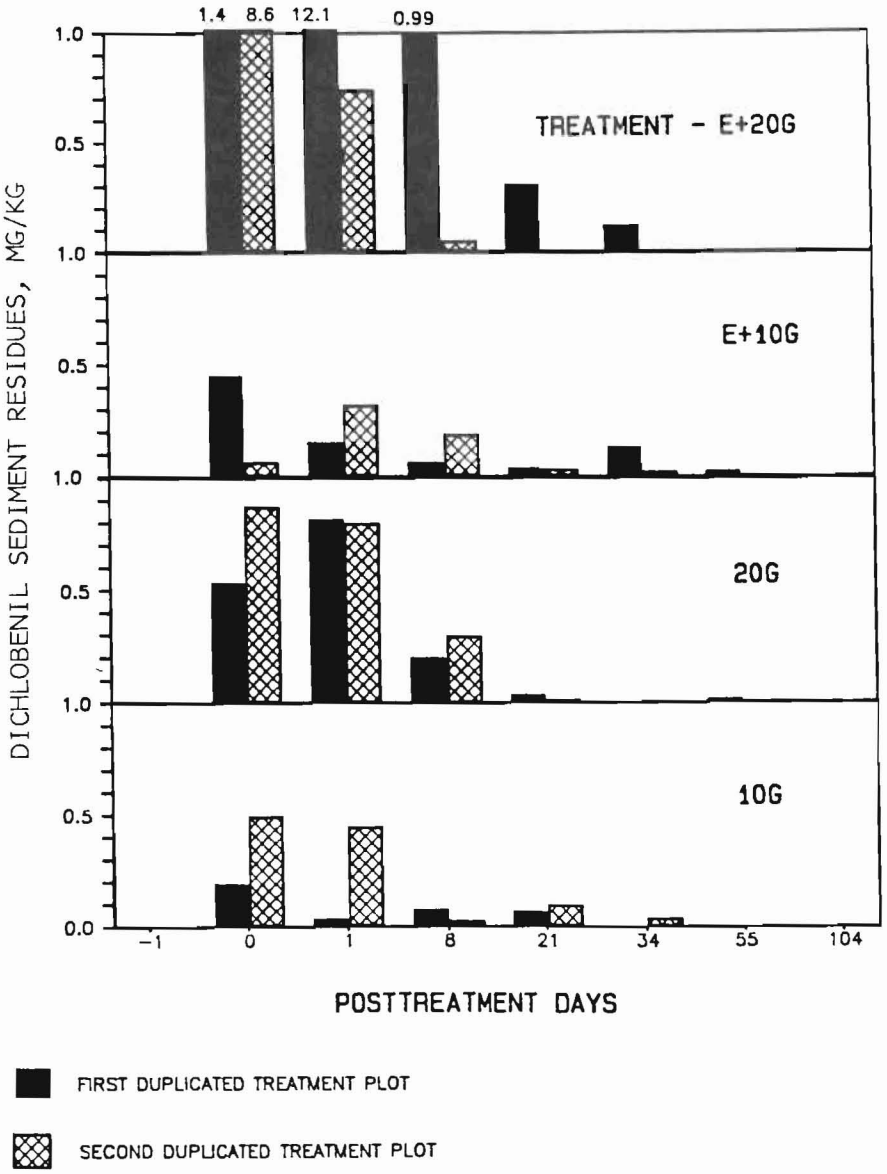

Figure 4. Dichlobenil sediment residues

Herbicide efficacy

23. Herbicide efficacy results indicate that dichlobenil applied to the pretreated endothall plots (E+10G and E+20G) retarded vegetative regrowth and reinfestation (Figure 5). Dichlobenil applied to the mature stands of plants (10G and 20G) resulted in little if any plant control. The 10G and 20G plots, which are not represented in Figure 5, contained approximately 100-percent cover (0-percent control) throughout the study, similar to that of the untreated reference plot.

Table 3

Sediment Residue Analysis: Dichlobenil*,**

Treatment	Plot No.	Sample Day -1	0	1	8	21	34	55	104
Reference	7	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
E+20G	1		1.430	12.100	0.993	0.312	0.124	<0.010	
	2		8.630	0.746	0.052	<0.010	<0.010	<0.010	
E+10G	5		0.454	0.156	0.065	0.040	0.134	0.027	
	8		0.068	0.323	0.191	0.034	0.024	<0.010	
20G	4		0.540	0.823	0.206	0.040	<0.010	0.018	
	10		0.878	0.805	0.302	0.017	<0.010	<0.010	
10G	9		0.195	0.038	0.079	0.070	<0.010	<0.010	
	11		0.500	0.453	0.028	0.100	0.041	<0.010	

* Corrected value expressed in milligrams per kilogram (0.010 mg/kg detection limit at 82-percent recovery).

** Composite sample from the center of the plot and the center of each quadrant.

24. The standing crop in the endothall-pretreated plots at the time of dichlobenil application (8 days after endothall application) was nonexistent (i.e., 99-percent control). The water column was void of mature, viable vegetation, and fragments of decaying plant material rested on the sediment or were floating on the water surface. Vegetative regeneration started to occur by posttreatment day 21 and continued to increase through the sampling period in the endothall-pretreated reference plots (without dichlobenil).

25. Dichlobenil applied after endothall (E+10G and E+20G) appears to have reduced standing crop regeneration through posttreatment day 55 (approximately 2 months). The vegetative standing crop was less in the E+20G plots than in the E+10G plots on posttreatment day 21. By posttreatment day 55, the standing crops within the E+20G and E+10G plots were relatively equal, but both were less than those in the endothall reference plots. At this time, hydrilla began to infest many of the once open plots, and watermilfoil began to regrow as well. By posttreatment day 104, hydrilla increased its abundance in many of the treated plots and, in one case, represented essentially 100 percent of the vegetative standing crop. The standing crop in the E+10G plots was considerably less than the E+20G plots, but only slightly

Table 4

Sediment Residue Analysis: 2,6-dichlorobenzamide*,**

Treatment	Plot No.	Sample Day -1	0	1	8	21	34	55	104
Reference	7	<10	<10	<10	<10	<10	<10	<10	<10
E+20G	1		11	22	<10	22	66	22	11
	2		11	20	22	12	<10	<10	<10
E+10G	5		<10	<10	<10	25	15	66	<10
	8				15	<10	32	<10	48
20G	4				<10	22	14	36	<10
	10				<10	<10	<10	<10	<10
10G	9				<10	12	<10	<10	<10
	11				<10	<10	<10	<10	<10

* Corrected value expressed in micrograms per kilogram (10 µg/kg detection limit at 100-percent recovery).

** Composite sample from the center of the plot and the center of each quadrant.

smaller than the endothall reference plots on posttreatment day 104. The effect of the dichlobenil treatment at this point was negligible. By post-treatment day 177, all but one of the plots were filled with mature, sometimes topped-out vegetation. The predominant vegetation of most plots on post-treatment day 177 was watermilfoil, while hydrilla dominated in other plots.

Discussion

26. Different initial plot conditions, as well as the use of two formulations of dichlobenil, contributed to the variability in the residue data obtained. Data differed not only among treatments, but also between plots of the same treatment. Each plot had unique characteristics (water volume, plant cover, etc.), as is the case in most aquatic field studies. Water exchange properties presumably differed between plots, as well. Those plots closer to the shore were probably influenced less by water flow than the plots closer to the main channel. Moreover, application of the two formulations of dichlobenil differed in order to achieve equal application rates of active

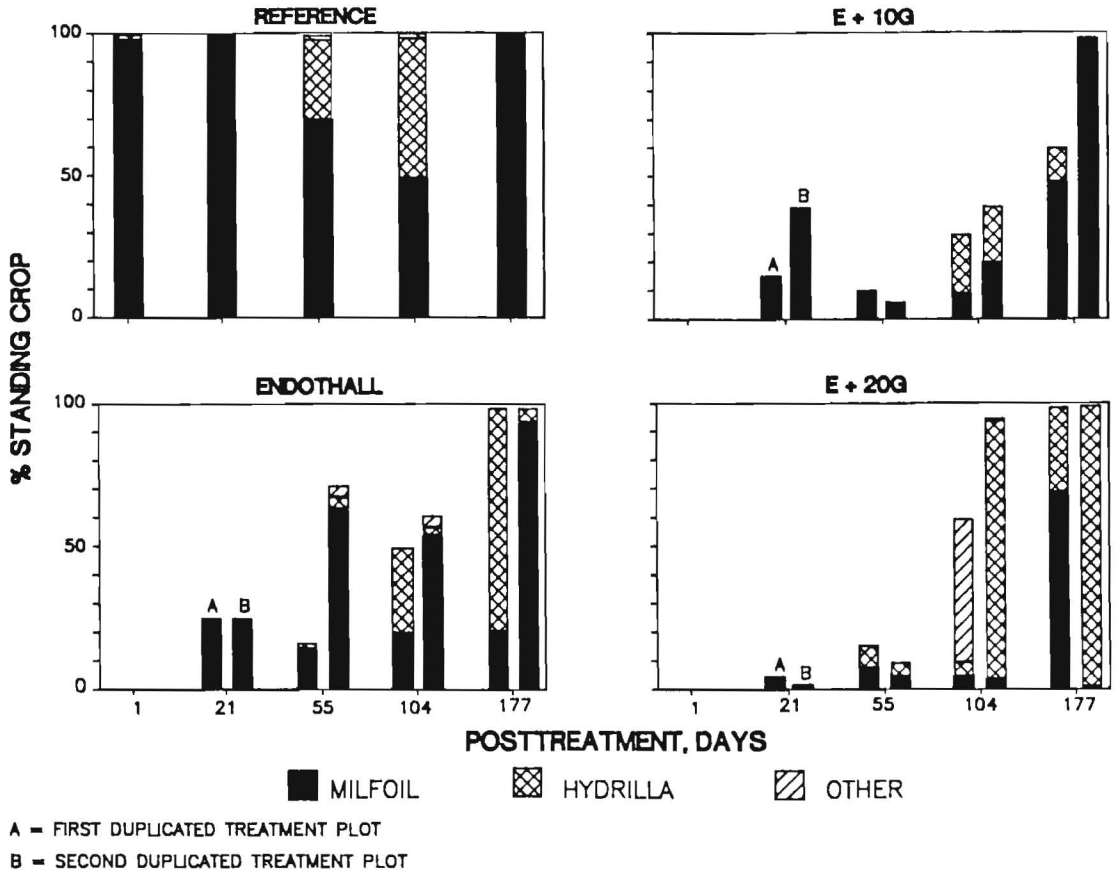

Figure 5. Effects of dichlobenil after vegetative knockdown

ingredient. Twice the mass of the 10-percent formulation (10G) was applied as the 20-percent formulation (20G), each pellet of the 20G formulation having twice the dichlobenil as the 10G. Consequently, residue persistence, dissipation, and herbicide efficacy results were somewhat ambiguous. Even though the data obtained are not qualified for statistical analyses, general trends can be established for dichlobenil residue persistence and dissipation in sediment and water and can be related to environmental fate and dispersion.

27. The results of this study and of previous field studies (Van Valin 1966; Cope, McCraren, and Eller 1969; Tooby and Spencer-Jones 1978; Terry, Robson, and Hanley 1981) indicate that dichlobenil persistence, dissipation, and dispersion in the aquatic environment are facilitated by the hydrodynamic characteristics of the system treated. Residue persistence, environmental fate, and dispersion will differ, for example, between small, closed, quiescent systems and large, open, flow-through systems. Results from the

present study, which was conducted in a large arm of a reservoir, demonstrate that partial treatment of larger, open systems (i.e., reservoirs and rivers) accelerates residue dispersion and dissipation. Residues released from the dichlobenil pellets from the sediment into the overlying water are mixed with the surrounding fresh water and, at the same time, are displaced by water moving in from upstream. Dichlobenil residues in the water of the present study peaked early after treatment and had dissipated by 50 percent in about half the time it took for the maximum concentrations to be reached in the water of the small, closed systems reported by Van Valin (1966), Cope, McCraren, and Eller (1969), Tooby and Spencer-Jones (1978), and Terry, Robson, and Hanley (1981). By the time it took water residues to reach maximum peaks in the previously cited studies, residues of the present study were at or below detectable levels.

28. It has already been suggested by Tooby and Spencer-Jones (1978) that localized treatments (<10 percent of the total surface area of the system) should cause no harm to the local fish population. Dichlobenil residue levels and the persistence of residues in the water of the present study further support this conclusion. The highest water residue concentrations in the present study (<100 µg/ℓ) were much lower than concentrations (710 and 1,280 µg/ℓ) producing gill damage in rainbow trout (Wiersma-Roem et al. 1978). In the present study, the amount of exposure time within the treated area was short, as indicated by the <21-day dissipation of the residues. Moreover, the fish could escape into the surrounding uncontaminated water, allowing the elimination of residues that may have been accumulated.

29. Dichlobenil's metabolite, 2,6-dichlorobenzamide, should pose no threat to nontarget organisms. Van Leeuen and Maas (1985) determined that 2,6-dichlorobenzamide was moderately toxic to a number of freshwater organisms: guppies, rainbow trout, daphnids, and algae. Toxic concentrations varied among the organisms involved. However, the levels of the metabolite residues that produce harmful effects (18 to 856 mg/ℓ) are extremely high, three to four orders of magnitude higher than the one detectable sample found in water (13 µg/ℓ) of the present study, as well as the detected concentrations found in sediment (<67 µg/kg). Van Leeuwen and Maas (1985) suggested that 2,6-dichlorobenzamide would not be expected to impose a great risk to local nontarget organisms when dichlobenil was used under operational conditions. Results from the present study further support this conclusion.

However, the conclusions both for dichlobenil and 2,6-dichlorobenzamide are directed toward nonbenthic organisms. Little is known about the effects of dichlobenil and 2,6-dichlorobenzamide on benthic organisms (e.g., shellfish).

30. Dichlobenil was effective in inhibiting young vegetative regrowth. Dichlobenil had little effect on the mature plant stands to which it was applied. However, when applied to plots pretreated with endothall, dichlobenil did appear to reduce the rate of vegetative regeneration. The effects seemed to last at least 2 months. Regrowth was much lower in the dichlobenil plots 55 days posttreatment than in the endothall reference plots. The efficacy results were not conclusive enough to determine the differences between the two formulations of dichlobenil (10G and 20G). The standing crops in the plots of both formulations (E+10G and E+20G) were very similar on posttreatment day 55. However, there were differences at 104 days posttreatment. It is not known what occurred between posttreatment day 55 and posttreatment day 104, but it can be assumed that the results at posttreatment day 104 are probably more reflective of plot variability than of herbicide persistence and efficacy. Dichlobenil control on vegetative regeneration and regrowth may have been more favorable if the application occurred 3 to 4 weeks after the endothall pretreatment. When the vegetation began regeneration in the endothall-pretreated plots, dichlobenil residues in the sediment had dissipated to almost below detectable levels (Figures 4 and 5). Higher concentrations of dichlobenil in the sediment during the initial stages of regrowth would have furnished the young vegetation the potential to accumulate more residues, resulting in greater efficacy.

Conclusions

31. Dichlobenil and 2,6-dichlorobenzamide residue persistence resulting from the application of dichlobenil under operational conditions in Lake Seminole, Georgia, was evaluated. Dichlobenil residues in the water were low (<100 µg/ℓ) and persisted for a short time (<21 days). Dichlobenil residues in the sediment were higher, the highest being 12.1 mg/kg, and persisted less than 104 days. The metabolite 2,6-dichlorobenzamide was detected in the sediment throughout the study at low concentrations (<67 µg/kg) and only once in the water (13 µg/ℓ). The residue results further support the evidence that the operational use of dichlobenil for treating localized areas of a large

system should not cause harm to the surrounding aquatic environment. Dichlobenil showed little ability in controlling mature vegetation. However, dichlobenil appeared to inhibit the vegetative regrowth and reinfestation that normally occur after vegetation is knocked down with endothall.

Recommendations

32. From the results of this study, the following recommendations are made:

a. Future field studies using dichlobenil should include residue sampling outside and downstream from the treated areas to determine residue dissipation and transport.

b. Residue accumulation, effects, and persistence in nontarget benthic and nonbenthic organisms need to be evaluated under an experiment use permit.

c. Both the 10- and 20-percent dichlobenil formulations should be evaluated in early spring, prior to or upon vegetative germination, to determine which is more effective in controlling submersed aquatic plants.

d. Sequential chemical application of endothall followed by dichlobenil needs to be further investigated to evaluate its effectiveness as a method for year-round submersed aquatic plant control.

e. Laboratory studies need to be conducted to determine dichlobenil concentration and exposure time relationships for the control of target plants and propagules.

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